SAPPHIRE SUBSTRATE, EPITAXIAL SUBSTRATE AND SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a sapphire substrate for growing a nitride semiconductor thereon, and an epitaxial substrate and a semiconductor device that utilize the same.

[0003] 2. Description of Related Art

[0004] Nitride semiconductors such as aluminum nitride (AlN), gallium nitride (GaN), indium nitride (InN) or aluminum indium gallium nitride ($Al_xGa_{1-x-y}In_yN(0 \leqq x \leqq 1, 0 \leqq y \leqq 1, 0 \leqq x+y \leqq 1)$) that is a mixed crystal of the former ones, can be applied to light emitting or sensing device and electron device, and therefore have been widely studied in researches on the crystal growth and application to semiconductor devices. Some applications thereof to light emitting diode and laser diode have already been commercialized.

[0005] Since nitride semiconductor cannot be grown into a large bulk of single crystal, it is usually hetero-epitaxially grown on a semiconductor growing substrate made of a different material such as (0001) sapphire (hereinafter referred to as C-plane sapphire), (11-20) sapphire, (0001) 4H—SiC or (0001) 6H—SiC.

[0006] Epitaxial growth techniques include metalorganic vapor phase epitaxy (MOVPE) method, molecular beam epitaxy (MBE) method, halide vapor phase epitaxy (HVPE) method and other, of which the MOVPE method is most commonly employed for its practical usefulness.

[0007] Semiconductor devices such as light emitting devices and electron devices that use the semiconductors such as those described above are manufactured by forming a structure where nitride semiconductor layers placed one on another by epitaxial growth over the entire surface of a sapphire substrate, processing the nitride semiconductor layers to form the device of desired configuration and forming electrodes thereon.

[0008] The nitride semiconductors that have been used in commercialized semiconductor devices have high levels of piezoelectricity due to wurtzite structure of hexagonal system that does not have inversion symmetry. **FIG. 17** shows a heterojunction of a nitride semiconductor consisting of two layers (a first layer **91** and a second layer **92**) formed from different materials one on another, where crystal growth is entirely oriented such that an interface **91**_a_ of the heterojunction is perpendicular to C axis **93**, which is referred to as C axis orientation. When a heterojunction is made by forming two layers that have different lattice constants one on another, therefore, a high piezoelectric field is generated due to a strain in the crystal.

[0009] The piezoelectric field has a significant influence on the characteristics of the semiconductor device, which will be discussed in the following description in the case of light emitting diode and laser diode.

[0010] Japanese Unexamined Patent Publication (Kokai) No. 11-177175 discloses a device made by forming an n-type buffer layer **103**, an n-type cladding layer **104**, an n-type guide layer **105**, an active layer of quantum well structure **106**, a p-type cap layer **107**, a p-type guide layer **108**, a p-type cladding layer **109** and a p-side contact layer **110** successively on a substrate prepared by forming a GaN layer **102** on a C-plane sapphire substrate **101** as shown in **FIG. 18**. Then the n-type cladding layer **104** and the p-type cladding layer **109** are exposed by dry etching, whereon an insulation layer **111**, a p-type electrode **112** and an n-type electrode **113** are formed so as to constitute a laser diode **135**. The active layer **106** is typically formed in quantum well structure as described above, which results in a change in energy band structure due to the strong piezoelectric field, leading to a problem with respect to improvement of characteristics.

[0011] In the case of a laser diode made by using other compound such as aluminum gallium arsenide, quantum well structure is intentionally strained so as to improve the characteristics such as lowering the threshold current of the laser through modification of the energy band structure of the semiconductor. However, in the nitride semiconductors that are used at present, a decrease in the threshold current of the laser can hardly be achieved by intentionally generating a strain. This is because the crystal has C axis orientation with respect to the direction of growth of the nitride semiconductor, and therefore the energy band structure does not change effectively.

[0012] In the case of a light emitting diode, too, the piezoelectric field generated in the active layer decreases the probability of carrier recombination, thus hindering the improvement of luminance.

[0013] Now an application to an electron device such as field effect transistor (hereinafter referred to as FET) will be described below. Normally heterojunction of GaN and aluminum gallium nitride (hereinafter referred to as AlGaN) is used so as to generate two dimensional electron gas in the interface thereof.

[0014] For example, Japanese Unexamined Patent Publication (Kokai) No. 10-335637 describes formation of an FET as shown in **FIG. 19**. First, an undoped GaN layer **115** having thickness of 2 μm is grown, via a low temperature buffer layer **114** having thickness of 30 nm, on the C-plane sapphire substrate **101**, followed by successive formation of an undoped $Al_{0.3}Ga_{0.7}N$ layer **116** having thickness of 30 nm, an undoped GaN layer **117** having thickness of 10 nm, an undoped $Al_{0.3}Ga_{0.7}N$ spacer layer **118** having thickness of 10 nm, an n-type $Al_{0.3}Ga_{0.7}N$ electron supplier layer **119** having thickness of 10 nm, an undoped $Al_xGa_{1-x}N$ barrier layer **120** having graded composition and thickness of 15 nm and an n-type $Al_{0.06}Ga_{0.94}N$ contact layer **121** having thickness of 6 nm. Then a source electrode **122**, a drain electrode **123** and a gate electrode **124** are formed thereby to obtain an FET **136**.

[0015] When the nitride semiconductor is grown on the C-plane sapphire substrate **101**, the nitride semiconductor having C axis orientation is obtained wherein an inversion layer is formed near the interface of the heterojunction under the influence of the piezoelectric field that is characteristic of the material, so that two dimensional electron gas having density of about 10^{13} cm^{-2} is formed in the interface even when no impurity is added. Therefore, the FET **11** made from this semiconductor becomes a so-called depression type FET where drain current can flow when the gate bias is zero.